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Review of Heating Elements used for Zirconium Fabrication

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***Abstract*— It has been almost four decades since the invention of nuclear power, which the world has never dreamt that it would create a revolution in the field of electricity. In this fast growing technological world, the importance of electricity has been growing leaps and bounds which limited its generation. The future world would completely rely on Nuclear Energy for its power generation. Nuclear energy is eco-friendly and eco-efficient of all the types of generations available. It can produce tremendous amounts of energy which can generate large amounts of electricity. Nuclear Fuel Complex (NFC), at which thesis work is made, is a house of production which manufactures reactor equipments along with processed radioactive element. This thesis is an overview of heating elements which are used in NFC to meet its production of Zirconium products.**

I. INTRODUCTION

Zirconium is one of the important elements used in the reactors to store radioactive elements, as it acts as a transparent medium to the neutrons passing through it, which are emitted during the fission or fusion process. Zirconium is obtained as a by-product from the mining of titanium minerals. The processing of this zirconium to seamless zirconium tubes is done at Zircaloy Fabrication Plant at NFC. The process requires two furnaces to turn the Zircaloy into sheets and then to seamless tubes. Zirconium is melted in a re-heater furnace, to obtain sheets and then shaped into tubes at vacuum annealing furnace. Thus, deciding a heating element for the furnace with respect to the environment, temperature and other factors is necessary. The purpose of this thesis work is to provide information of different types of heating elements used in the furnaces of Nuclear fuel Complex for the production of seamless zirconium tubes.

Heating element is defined as the element which converts the electric current through it, into heat energy through the process of resistive or joule's heating. When electric current passes through an element it encounters resistance and thus heat is generated. Heating element is the critical part of a furnace and has to be chosen with utmost care.

II. HEATING ELEMENTS USED AT NFC

Metal type heating elements are more reliable for high temperatures and can withstand a temperature up to 1500^0C. The heating element may be wire or ribbon, straight or coiled. The most common classes of material include,

a) Kanthal
b) Nichrome

Kanthal

Kanthal is the trademark of iron-chromium-aluminium (FeCrAl) alloy, which is used for wide range of high temperature conditions. Kanthal is widely known for its robustness at high temperatures. At high temperatures, Kanthal alloy forms a protective layer of aluminium oxide (alumina) which acts as an insulator but has good thermal conductivity. Thus heat generated is dissipated at a faster rate. Kanthal has a melting point of 1425^0C. Based on the composition of iron-chromium-aluminium, Kanthal is further classified into

- Kanthal APM
- Kanthal A-1
- Kanthal A
- Kanthal AF
- Kanthal AE
- Kanthal D
- Alkrothal

Nichrome:

Nichrome is a non magnetic alloy of Nickel and Chromium, which has 80% nickel and 20% chromium. It has relatively high resistance which makes it an ideal material for heating element. It forms an adherent layer of chromium oxide when it is heated and the material beneath this layer is not oxidized and hence averts the wire from breaking. Nichrome, being highly resistant towards corrosion and oxidation at elevated temperatures, makes it more preferable than other heating elements. In addition to this, it has an ultimate tensile strength of 105,000 PSI and a melting point of 1400^0C. Nichrome based on its chemical composition is divided into four classes:

- Chromel
- Inconel
- Hastelloy
- Constantan.

III. FACTORS INFLUENCING THE SELECTION OF HEATING ELEMENT:

There are many factors to be considered while choosing or designing a heating element for the furnace. At high temperatures, the physical and mechanical properties of the heating element become very influential. Some of the factors and their relation with the heating element are as follows.

- Surface loading

The amount of electrical or thermal load applied on a square centimetre of area is called the Surface loading. It is expressed in terms of W/Cm^2. If two elements have same rating, then the wire with high surface load can be made using small quantity of wire, but the expected life will be short.

- Furnace environment

While the selection of the heating element, furnace environment plays a vital role. For a given heating element used in Zircaloy Fabrication Plant can have two types of furnace environment, i.e air and vacuum. Furnace environment decides the extent of corrosion of the heating element. Thus heating elements must be chosen according to their suitable environment.

- Tensile Strength

Tensile strength is often referred to as ultimate tensile strength. It can be defined as the maximum stress that a material can withstand without breaking, when it is subjected to pulling or stretching. While designing a heating element, an element with highest tensile strength has to be chosen.

- Creep

Creep is one of the significant factors to be considered while designing the heating element. Under the influence of mechanical stresses, the tendency of a solid material to deform permanently, as a result of long term exposure to high levels of stress below the yield strength of the material is called as creep. It maintains a direct relation with temperature, which means as the temperature increases, creep also increases.

- Electrical resistivity

Electrical resistivity gives the ability of a material to oppose the flow of electric current. The electric resistivity of a heating element has to be high, so that it can offer maximum resistance to the flow, thus generating large amounts of heat.

- Coefficient of thermal expansion

The fractional change in size per degree change in temperature at constant pressure is given by coefficient of thermal expansion. For a heating element to have longer life and efficient performance, it is necessary that the coefficient of thermal expansion must be high.

- Melting point

Melting point is the temperature at which a solid material is converted from its solid state to liquid state. Elements with higher melting points are preferred for a heating element so that they do not get deformed easily.

- Density

Density is defined as the mass per unit volume. When considered for a heating element, the density must be minimum so that the overall weight of the heating element is reduced which in turn reduces the cost.

IV. FURNACE SPECIFICATIONS

Zirconium is an important element used to store uranium. Zirconium, unlike the other elements when used in the storage of uranium, acts as a transparent medium for the neutrons, which pass through it during the fission process in the nuclear reactor. Thus, it plays a significant role in the fission process. Raw zirconium is obtained as zirconium soil and transformed into pallets. These pallets are then melted to obtain zirconium products of desired shape and size. To carry out the fabrication process, NFC has setup two furnaces.

1. Re-heater Furnace:

Specifications:
Power Rating: 180KW
Voltage: 440V
Environment: Air
Operating Temperature: 1100^0C
Construction:
A re-heating furnace comprises of a concave shaped chamber which has 12 grooves on each side of its interior and 14 grooves across. The total length of the furnace is about 3.5 metres. The heating element used in the furnace is Kanthal A-1. The resistivity of this material makes it suitable to be used in this furnace. The maximum temperature up to which it can be used is 1400^0C.

2. Horizontal Vacuum Annealing Furnace

Specifications:
Power Rating: 360 KW
Voltage: 60V (1-phase)
Operating current: 2200 Amps
Environment: Vacuum under the pressure of 10^{-6} mbar.
Construction:
Vacuum annealing furnace is used for the production of low contaminated, seamless zirconium tubes, at high temperature in a vacuum environment. It consists of three single phase transformers of 60V each, connected to three thermocouples. To achieve control over the temperature in the furnace, it is equipped with PID controller and Firing angle control. The maximum temperature which could be generated in the furnace is over 1500^0C.

V. ALGORITHM FOR CALCULATING SURFACE LOAD

Surface Load becomes one of the critical factor while designing the heating element for any furnace. Greater the surface load, greater will be the thermal stress and shorter will be the length of the wire. Hence, it is necessary that the surface load for a heating element must be as low as possible for a given length of the wire. To calculate the surface load we have standardised dimensions such as the spacing, diameter etc of the wire, provided by the manufacturers. The following algorithm provides a best method to calculate the surface load of the given heating element.

1. The standard dimensions for the diameter and spacing required and electrical resistivity at 20^0 C, for the heating element are provided by the manufacturers. Consider the heating element Kanthal A-1 used in a re-heater furnace.
   The standard dimensions specified for this heating element are:
   D=25mm, d= (5-8) D; s= (2-3)d
   ρ at 20^0 C=1.45ohm mm^2/m
   Where, s is the spacing, d is the diameter of the groove and ρ is the electrical resistivity.
2. The rating of the furnace per phase is given as 180/3 KW= 60KW. Calculate the resistance of the material at this rating, using the formula R= V^2/P= 440*440/60000= 3.22 ohm
3. The value of diameter of the wire used in NFC is d = 4.1mm. Calculate the area using the formula A= πr^2 ,where r=d/2 is the radius. Therefore A= 13.19585 mm^2
4. Calculate resistance per meter using the resistivity value i.e, ρ =1.45 ohm mm^2/m. Hence,
   Resistance/meter= 1.45/13.195= 0.1098ohm
5. This resistance is calculated for one meter length. Hence the length for 3.22ohm will be given by 3.22/0.0198 = 162.62
6. Calculate the surface load of the material which is gives as W/cm^2.

$$Cm^2 = \pi*d*l= 3.14*0.41cm*29.364*100= 3780.3216$$

Surface load= 60000/3780.3216=15.827

7. From the graph given by the manufacturers, the surface load for the temperature of 1100^0C must be as minimum as possible.
8. Hence, the iteration is once again carried out for power ratings 30KW and 20KW and the rating which gives the least surface loading will be chosen.
9. By choosing a rating of 30KW, the number of coils that are to be connected in parallel are 2 and by choosing a rating of 20KW, the number of coil to be connected in parallel are 3.
10. The values of surface loading for the rating 30KW and 20KW are 3.96 and 1.76 respectively.
11. Also, the length of the wire of the heating element is an important aspect to be considered. The length of the wire is to be chosen so that maximum amount of the heating element must be accommodated in the furnace without any wastage of the material so as to achieve uniformity.

VI. Specifications of Heating Elements Used in NFC

The following tabular column gives the complete details of the heating elements used in Horizontal Vacuum and Re-heating furnace.

Heating Element	Power Ratings	Voltage	Radius (mm)	Surface Load	Heat Output
Nichrome	360KW	60V (1-phase)	25*3 (strip)	2.0	760^0 C
Kanthal A-1	20KW (3 coils in parallel)	440V	4.1	1.6	1000^0C

VII. Conclusion

We can conclude that a clear understanding of the various methods and techniques used for the selection of heating elements in the Zirconium Fabrication Plant is essential for working and operating in variant environments. We also develop an idea of how to design a heating element and the different types of heating elements that are in use at present in the industry.

References

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